ABSTRACT

Indian cities rely predominantly on buses for public transport. The issues of performance measurement and efficiency analyses for the bus company have been gaining significance due to severe operating conditions and financial constraints in which these bus companies provide the service. Performance is defined as the levels of success of the service with respect to different parameters such as quality of service, cost effectiveness and safety. Performance is measured in terms of operational efficiency and financial efficiency. Operational Efficiency of an organization is the ability to utilize its available resources to the maximum extent. Financial Efficiency is a measure of the organization's ability to translate its financial resources into revenue. Public bus transportation plays a pivotal role in India in bringing about greater mobility both within and between urban and rural areas. Through increased mobility, road transport also contributes immensely to social and economic development of different regions of the country. Public transport is provided by surface road transport using buses by the State Road Transport Undertakings (SRTUs) and by private operators.
In this thesis, scientific analysis of the performance of SRTUs is carried out at different levels considering physical and financial parameters through multivariate techniques, non-parametric techniques and qualitative techniques. A comprehensive study on all the SRTUs of Karnataka at depot, division level are done and determined which quantitative method is suited for depot level and division level studies. From quantitative and qualitative studies of SRTUs strategies are developed and recommendations are made to improve the performance of SRTUs. Further, in addition to Bangalore metropolitan transport corporation (BMTC) performance analyses, the routes are analyzed to reduce the dead kilometer.

Major contributions from this work:

1. Both inter and intra city operations of the public transport corporation in the state of Karnataka have been exhaustively analysed using operational and financial parameters.
2. Large amount of data over a long period has been collated from State road transport units and a standard format has been developed for collecting both operational and financial parameters for SRTU's.
3. A generic framework and plan for performance evaluation of SRTU's has been developed using ratio and benchmarking analysis, and, non-parametric and multivariate techniques like DEA (constant return to scale (CRS) and variable return to scale (VRS)), DEA-principal component analysis (PCA), DEA- bootstrapping. These analyses have been carried out at different levels, like transport corporations level (KSRTC, NEKRTC, NWKRTC, BMTC), division level (33 divisions), and Depot level (193 depots).
4. Non parametric and multivariate Models have been developed and validated using DEAP and GAMS software before embarking on the above detailed analyses.
5. Analytical hierarchy approach (AHP), which is multi criteria structured technique, has been adopted to evaluate and analyze performance of the SRTU's, divisions and depots based on qualitative and quantitative data.
6. User and operator perception studies of different SRTU's of Karnataka have been done to evaluate the performance of these corporations from qualitative techniques.
7. From these comprehensive non parametric techniques, the efficiency of the SRTU's have been evaluated and found that KSRTC has been the best operating unit among the SRTU's considered for the study. The same has been observed from the AHP as well as perception surveys carried out as part of this thesis.
8. Operation and financial performance including profitability studies of Mysore urban transportation (Mysore city transport division) has been carried out before and after implementation of intelligent transport system (ITS).
9. The dead kilometer minimization model was formulated, which is a mixed integer programming problem, to get the optimal solution considering the capacity of the depot and time period of operation for the chosen network. An optimization technique has been developed for solving the dead kilometer problem in the operations of BMTC buses for the Volvo division (division operates 794 schedules). The alternative depot locations have been identified to reduce the dead kilometer, leading to large amount of savings for the corporation.
10. From the detailed analyses using non parametric techniques, multivariate and multi-criteria techniques along with perception surveys, strategies and recommendations have been arrived at to improve performance of the public transport corporations.

This thesis consists of nine chapters and they are as below;

Chapter 1 provides a brief introduction of public bus transport systems in India, their problems and need for performance evaluation of SRTUs. The impacts study of Mysore ITS, dead kilometer minimization problem for BMTC along with evaluating the performance of SRTUs by quantitative and qualitative data. This chapter provides the objective of the work and scope of the work. The main objectives of this research are

1. To develop a generic framework and plan for evaluation by identifying the performance indicators and data sources for evaluation.

2. To evaluate the performance of public transport operations at different levels, such as divisions, depots and routes of corporations in Karnataka by using both quantitative and qualitative data. To recommend appropriate technique to evaluate the performance of SRTUs.
3. To improve the efficiency in the corporation by developing strategies.
4. To evaluate the performance of Mysore City Transport Division before and after ITS implementation. Also to understand the changes in the performance of Mysore City Transport Division before and after ITS implementation by carrying out survey of both user and operator.
5. To evaluate the performance of BMTC.
6. To minimize the dead kilometer for BMTC routes by using appropriate optimization technique.

The scope of the study is to evaluate the performance of all depots, divisions of SRTUs of Karnataka and also to study the impact of ITS on Mysore city bus transport, by using multivariate and non-parametric technique. Multivariate and non-parametric techniques analyze the quantitative data (physical and financial parameters) of the depots, divisions and SRTUs optimally to estimate the relative efficiency. To achieve the above objectives first data from these transport corporations are collected and analyzed quantitatively. A qualitative study is also done by collecting user and operator perception about the SRTUs and impact of ITS project using questionnaire survey. Further, the routes of BMTC are analyzed to reduce the dead kilometer by solving dead kilometer minimization problem. The efforts have been put to improve the efficiency of SRTUs by developing strategies.

Chapter 2 reviews the published literature relevant to performance measurement of public transport systems, both by qualitative and quantitative techniques, impact evaluation of Intelligent Transport System (ITS) and methods for dead kilometer minimization problem in case of public transportation. This chapter reviews the previous research work performed on analysis of performance measure using ratio analysis and benchmarking, non-parametric analysis such as data envelopment analysis (DEA), multivariate analysis such as principal components analysis (PCA), analytical hierarchy process (AHP) and bootstrapped-DEA.

Chapter 3 gives the details of the study area considered for the performance evaluation of public bus transportation. The study area selected is Karnataka state. The operational characteristic of all the SRTUs of Karnataka are discussed in detail. Karnataka state road transport corporation (KSRTC), North West Karnataka road transport corporation (NWKRTC) and North East Karnataka road transport corporation (NEKRTC) are the three SRTUs they serve the urban as well as rural area. The majority of these SRTUs operate the buses for intercity transportation. BMTC is another SRTU which operate intracity buses for Bangalore city. The operational characteristics of Mysore city bus transport divisions are also discussed in view of Mysore ITS impact study. The dead kilometer of BMTC routes are presented to know the dead kilometer issue in BMTC routes along with performance analyses.

Chapter 4 discusses in detail the data collection and the methodology to measure and compare the performance of state road transport units (SRTUs) of Karnataka. The annual quantitative data is collected for the performance evaluation of three SRTUs (KSRTC, NWKRTC and NEKRTC) at divisional level for seven years from 2004-05 to 2010-11. For depot wise performance evaluation three years annual data from 2008-09 to 2011 were used. To evaluate the impact of Mysore ITS annual data for five years from 2009-10 to 2013-14 were used. In case of BMTC also the performance evaluation is done at Divisional level as well as at depot level for the five years based on annual data from 2009-10 to 2013-14. Depot level analysis is done only for central (Volvo) division of BMTC and further optimization of dead kilometer for schedules of central division of BMTC were also done. KSRTC has 71 depots and 13 divisions. NWKRTC has 46 depots and 7 divisions, NEKRTC has 43 depots and 8 divisions, BMTC has 35 depots and 5 divisions, and Mysore urban division (for Mysore ITS impact study) has 3 depots. The methodology to evaluate the performance of SRTUs by non-parametric and multivariate techniques for quantitative data using DEA-CRS (constant return to scale), DEA-VRS (variable return to scale), PCA-DEA, bootstrapped-DEA and AHP have been discussed in detail. This chapter also discusses the methodology adopted for users and operator perception study for Mysore ITS and intercity bus transport of SRTUs of Karnataka.

Chapter 5 gives the results of ratio analysis and benchmarking technique applied to depots, division and SRTUs of Karnataka. The parameters used are operational and financial parameters, to find the operational and financial efficiency in terms of how much saving can be achieved with respect to benchmarked depot or division or SRTU. The total savings are the summation of savings from the fuel, savings from the staff and savings from capital expenditure. In addition, this technique is used to know the impact of ITS on Mysore city transportation before and after ITS implementation. The operational parameters viz. vehicle utilization, staff productivity, fuel consumed (KMPL) and effective kilometer are considered. The financial parameters viz., earning per kilometer, cost per kilometer and profitability are considered. From these parameters the performance of DMUs is found in the form of total savings when compared with top performing entity in their group. Ratio analysis and bench marking technique was applied to depots, division of all the three SRTUs (KSRTC, NWKRTC and NEKRTC). From Ratio analysis and bench marking technique, in case of overall analysis of 158 depots of 3 SRTUs (KSRTC, NWKRTC and NEKRTC) are considered together. It has been observed that for Dharwad depot of

Hubli division, the total savings value would have been 610.15 Million Rupees which is the highest among all the depots analyzed. Gangavati depot of Koppal division, the total savings value would have been 24.10 Million Rupees which is the lowest among all the depots analyzed indicating that its performance is high. Similarly for division wise analysis, 28 divisions of all the 3 SRTUs (KSRTC, NWKRTC and NEKRTC) are considered together. It has been observed that for Mysore urban and Hubli division the total savings value is of the order of 900 Million Rupees and 1200 Million Rupees respectively. Bangalore central, Koppal, Yadgiri, Chikmagalur, Chikkaballapur and Chamarajanagar divisions have the least savings value indicating that its performance is already well tuned. In case of corporation wise analysis, KSRTC, NWKRTC and NEKRTC are analysed and it is observed that, for NWKRTC the total savings value is of the order 1400 Million Rupees which was the highest among all the SRTUs analyzed. KSRTC has less total savings value compare to other two SRTUs indicating that its performance is already well tuned. In case of Mysore ITS impact studies, from the data (operational and financial parameters) it is also observed that, profitability for all the depots of Mysore city transport division (MCTD) was increasing in the year 2010-11 and 2011-12, but started decreasing in 2012-13 and 2013-14. This trend has to be viewed in depth, as these years are after implementation of ITS. The year wise expected savings for three depots of MCTD are calculated. It has been observed that, the savings would have been 51.70 million Rupees for Kuvempunagar depot in the year 2009-10 and it would have been 21.83 million Rupees in the year 2013-14. From ratio analysis and benchmarking technique, it is concluded that, the ratio analysis and benchmarking helps us in studying each performance parameter in isolation and express the slack or surplus in the form of saving. However the complex systems such as public bus transportation organizations have many parameters and constraints. For multiple inputs and multiple outputs, a non-parametric technique (DEA) may be used.

Chapter 6 gives the results of data envelopment analysis (DEA) applied to depots, division of all the three SRTUs (KSRTC, NWKRTC and NEKRTC) to understand the performance of depots, divisions and the entire corporation by calculating relative efficiencies and also to set the targets for inefficient depot or division. The other techniques like principal component analysis (PCA) and bootstrapping have been used to improve the results found from DEA. Analytical hierarchy process (AHP) results build the confidence on DEA. Data envelopment analysis is used for finding the performance of depots, divisions and the SRTUs. DEA is capable to handle multiple input and multiple outputs. To quantitatively evaluate the performance of 3 SRTUs of Karnataka at depot level, division level and at corporations level of 3 SRTUs. DEA-CRS and DEA-VRS techniques have been used. From depot wise performance analysis it is concluded that DEA-CRS efficiency values are having the range of 0.482 to1.00 and DEA-VRS efficiency values are having the range of 0.879 to 1.00. Similarly from division wise performance analysis it is concluded that DEA-CRS efficiency values are having the range of 0.75 to1.00 and DEA-VRS efficiency values are having the range of 0.965 to 1.00. To find the efficiencies values from DEA-CRS and DEA-VRS model DEAP (Coelli, 1996) is used.

Within DEA context, problem of discrimination between efficient and inefficient decision – making units often occur which has been observed when only DEA model was applied to data. So to improve the discrimination in DEA results, PCA is applied to DEA (PCA-DEA). PCA-DEA model has shown the discrimination between the efficient and inefficient DMU's which was not observed in DEA. According to PCA-DEA there are inefficient DMUs and they depend on like total number of vehicles, employees, fuel consumption, number of schedules, effective kilometre, accident rate, breakdown rate and staff per schedule.

When the numbers of DMUs are less compared to the input and output parameters used, the efficiency obtained from the DEA model will have an upward bias. In order to obtain the accurate efficiency values use the bootstrapping technique for the DEA which will remove the bias and this can be seen in the results. In this study it is concluded that Bootstrapped-DEA is the best technique to evaluate the performance of SRTUs, as it takes care of discrimination problem of DEA model. Dual program is used to find the slack or surplus of an inefficient DMU. From bootstrapped-DEA and AHP results it is found that, Depot-4 of Bangalore central division is top performing. The reason is that this is a Volvo (Air conditioned) bus depot, which always have more profit margin and other complaints like breakdown and accidents are very less as these buses are premier service buses of KSRTC. Also Bangalore central division is top performing division as per the results. From corporation level analysis, it is conclude that the KSRTC is the top performing corporation and NWKRTC requires more attention towards improving the performance.

From non-parametric analysis results it is difficult to conclude on the impact of ITS on Mysore city bus transportation. However, from AHP results it is observe that the efficiency of Bannimantapa depot is improving.

In this work for DEA-CRS and DEA-VRS, DEAP has been used. The GAMS (Version 24.2.2, 2014) software is used to find the efficiency values for PCA-DEA model by writing codes in GAMS to solve range direction measure (RDM) model. For finding principal component (PC) factors in case of PCA-DEA, Statistica software was used. In case of bootstrapped-DEA, to find the pseudo efficiencies easyfit software has been adopted.

Chapter 7 discusses in detail the user and operator perception study for qualitative performance analysis. From this study, it has been observed that SRTUs of Karnataka have the scope for improvement with respect to cleanliness at both inside the bus and bus stand, improvement of crew behavior with passenger, reduction in

fare, increase in bus frequency, rest room facility for crew, vehicle maintenance. From the qualitative data analysis, it is conclude that, KSRTC is top performing SRTU compare to NWKRTC and NEKRTC. So the qualitative and quantitative analysis concludes that KSRTC is the best among the three SRTUs.
To know the effect of project before and after ITS implementation on Mysore city bus transportation, user and operator perception study is done. According to crew of Mysore city bus transport, authority should take suitable measures to create awareness about ITS to commuters of Mysore city, by advertising ITS system at bus stands, bus stops, inside the bus, through the newspaper and television. According to crew, ITS has not affected to their operation or the revenue of the corporation, they also opined that commuters were not getting attracted in spite of ITS, ITS equipments are not operating properly, ITS information is not accurate and they are opining ITS overall performance is poor. So awareness must be created within crew by making them aware of benefits they and public will get if ITS is implemented successfully. Officials of Mysore city bus transport opined that ITS is useful for optimizing routes, vehicle tracking, for crew management and for passenger information. From the above observations, it was very clear that, the ITS project is still going through development and stabilization phase during the study period, due to which total intended benefits could not be accrued to the people of Mysore.

Chapter 8 discusses comprehensively the performance evaluation of BMTC along with a scheme for minimizing dead kilometers of the Central division of BMTC has been carried out. For performance evaluation, five years annual data (2009-10 to 2013-14) of BMTC is used. From ratio analysis and benchmarking technique it is observed that the maximum savings that can be saved were observed for the year 2013-14 and it was 1204.97 million Rupees for Volvo division when all the divisions of BMTC are analyzed, but the maximum total expected saving from all the depots of Volvo division were 389.74 million Rupees for the same year 2013-14. From this it is observed that this technique will take into account only the top performing entity irrespective of type of vehicle. So when only Volvo depots (buses) are analyzed the expected savings dropped down from 1204.97 million Rupees to 389.74 million Rupees. From this observation, it is concluded that, the Volvo buses are gaining importance and they are well accepted by commuters of BMTC.
Data envelopment analysis was carried out for the same five year period, the year wise efficiency of each division of BMTC were obtained by DEA-CRS, DEA-VRS,PCA-DEA and Bootstrapped-DEA. From the results it was concluded for this type of data bootstrapped-DEA is the correct method. AHP results show that East division has good performance compared to other divisions. The DEA results for depots of Volvo division also concluded that bootstrapped-DEA is the correct method for small groups of DMUs and parameters. In case of depots of Volvo division, from AHP results it was observed that, depot-25 and depot-28 were performing better compared to other depots, before establishment of depot-18. However, it is also observed that, the performance of depot-07 and depot-13 has been improved by establishing depot-18. From both ratio analysis and benchmarking technique and bootstrapped-DEA results, it can be observed that, the performance of Volvo division is improving over the period and it is emerging as the best performing division.
Comprehensive study of dead kilometers of all the routes in BMTC along with a scheme for minimizing dead kilometers of Central division of BMTC has been carried out using mixed integer linear programming. The dead kilometers of Central (Volvo) division which was earlier 3573.9 kilometers reduced to 2381.9 kilometers, thereby reduction of 1192 dead kilometers which resulted in saving of Rupees 73904 per day and if further calculated, savings are Rupees. 2.22 million per month. Analysis of percentage of dead kilometers of depots helps in allocating new routes and choosing proper location for new depots while minimizing dead kilometers.

Chapter 9 summarizes the entire thesis work and also list the conclusions arrived based on the results of quantitative and qualitative data analysis. The major conclusions include that,

1. A generic framework and plan for evaluation by identifying the performance indicators and data sources for evaluation has been developed.
2. The performance of public transport operations at different levels such as divisions, depots and routes of corporations in Karnataka by using both quantitative and qualitative data has been carried out.
3. Appropriate techniques to evaluate the performance of SRTUs have been recommended.

This chapter also gives details on the Strategies and Recommendations for improving the performance of SRTUs of Karnataka and also discusses about the future scope of work in this area. The major strategies include:

1. Developed tool can be used to analyze the monthly/weekly/daily data for evaluation of performance with respect to ratio analysis and benchmarking, DEA, PCA-DEA and bootstrapped-DEA.
2. The user and operator study should be carried out regularly to perceive the requirements or difficulties faced by both user and operator. Qualitative data can be collected using social media tools and used on continuous basis to evaluate the performance.

Other recommendations and strategies are listed in the thesis.